R. Larson
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C.S. Draper Laboratory
Division of Massachusetts Institute of Technology
Cambridge, Massachusetts

Group 23N - Apollo Project Memorandum

To: Distribution

From: W. Tanner /W.E.T.

Date: 16 February 1971

Subject: Apollo 14 Lunar Module Navigation and Guidance System, Preliminary Report on Landing Radar Performance During Descent and Landing in Fra Mauro Highlands.

Refs:
(1) MIT-Draper Laboratory, Group 23N Memorandum of June 10, 1970 by W. Tanner, Landing Radar Model for Prediction of Radar Acquisition Boundaries.
(2) MIT-Draper Laboratory, Group 23 N Memorandum of 11 February 1970 by W. Tanner and Ann Hathaway, Performance of Landing Radar During Powered Descent of Apollo 12.
(3) MIT-Draper Laboratory E-Note #2548 by W. Tanner, Interaction Between Radar Sensor and Navigation and Guidance System During the Apollo 12 Descent to the Moon.

Summary

During the descent to the Moon the LM Landing Radar acquired very late and only after recycling of its circuit breaker. Acquisition was about 1 minute before a mandatory mission abort decision had to be made. The first slant range measurement was in error by about +13000 ft and settling of the range tracker error after appearance of range data good required about 8 to 10 seconds rather than an expected 4 to 6 seconds. Once radar updating had been enabled by the Astronauts, the radar provided very accurate range and velocity data up to touchdown with only a 6 second interruption during HIGATE antenna position change. The navigation system's error vector for velocity at the time of touchdown was 0.03, -0.28, -0.05 ft/s in LR antenna coordinates. This is the best performance of any system so far. There were no radar drop-outs and no stealing of trackers by agitated lunar dust because of the positive downward motion during Astronaut control of the vehicle in P-66. The initial acquisition problem of the radar must

be attributed to the use of the system outside its design limits. A similar failure had been observed in June 1970 and was reported in Reference 1. The failure can be avoided by procedural recycling of the radar's circuit breaker, after the vehicle has reached an altitude of less than 40000 ft. The problem with slow settling of the range tracker requires further investigation, but there is no need for modifications of computer programs. Current procedures prevent false radar inputs. Updating of the radar models in the various simulators to incorporate acquisition failure modes may be desirable.

The Acquisition Problem

The failure of the Apollo 14 Landing Radar to acquire early in the powered descent was suspected to be related to the modifications in the erasable memory of the LGC that were entered shortly before and after DPS ignition. Table I shows a time-line of the events which may have affected radar operation. In it can be seen that the critical change of the radar's range-scale logic occurred in a rather quiet period prior to ignition of the engine and at least 4 seconds before any DSKY manipulations. Once the radar had switched to low range scale, the radar's frequency search range was reduced and did not longer cover the relatively high Doppler frequencies. The radar could not have recovered by itself until the slant range was below 12000 ft (about 8500 ft ALS) and a false acquisition would have been likely. Slow recycling of the circuit breaker was the only remedy and this has obviously saved the Apollo 14 mission.

The switching into low range scale occurred at an altitude of 51449 ALS and at an estimated slant range of 63000 ft. The spacecraft was at 10.51°s, 14.65°E over the crater DOLLOND. This impact crater is about 10 km in diameter, has steep walls and may be an area of very high radar reflectivity. The vehicle velocity at the time was 5575 ft/s relative to the terrain and the closing velocities along radar beams 1, 2 and 3 were 3145.4, 2949.5, 5116.8 ft/s respectively. Under these circumstances it was likely that the Doppler beams 1 and 2 already had acquired for some time, a conclusion that is substantiated by the fact that the range data good discrete had been on and off several times before the switching to low range. From the experience reported in Reference 1 one can further conclude that the strong return signal from crater DOLLOND produced range tracker acquisition on a spurious receiver signal within the trackers search range that had been produced by a

tracker input signal of about 205 kHz (145 kHz range + 60 kHz Doppler). Gradual change of this spurious signal through a frequency range equivalent to 2500 ft slant range must have triggered the switching to low range.

In Reference 1 it was pointed out that at altitudes above 40000 ft the Landing Radar might acquire in such a failure mode depending on the received signal strength. In experiments with the P-32 Landing Radar at MIT we had noticed indicated ranges in the order of 10000 ft and below, when an input equivalent to more than 60000 ft was simulated to the range tracker. We did not observe at that time the switching to low range scale, but the frequency tracker usually hung up on the spurious signal and recovery was only possible by switching to "self-test". If the radar goes to low range scale, the only recovery is by <u>slowly</u> recycling the circuit breaker.

The erroneous switching to low scale must be considered as a normal potential failure mode of the radar, when power is applied to the radar above an altitude of 40000 ft. There is no indication that there was any malfunction of the circuits, the components or of the installation of the radar. Changes from a standard descent trajectory may modify the altitude limit, since the radar performance is also affected by attitude angles and the magnitude and direction of the velocity vector.

<u>Settling Time of Range Data After Proper Acquisition</u>

At 108:08:49.8 AET the LR circuit breaker had been recycled and the radar was searching again in "high scale" configuration. <u>Twenty</u> seconds later the velocity data good appeared, followed immediately by the range data good. At that time the range beam #4 intercepted the ground at 3.96^{o}s, 16.37^{o}w, 11 km ENE of FRA MAURO Y, in a relatively level area. The elevation of that terrain is about 1736 km, the true slant range was in the order of 23000 to 25000 ft. The radar indicated initially 38164 ft and settled to a reasonable value only 8 to 10 seconds later. The Astronauts had the cool to wait for 14 seconds before they enabled radar updating of the state vector at 108:9:35.8 at a displayed DELTAH of -29 ft, an almost incredible correlation between inertial system data and terrain data. The relatively long settling time for the radar's range tracker may be explained by strong received signals triggering the switching of the tracker from search to tracking mode relatively early.

Radar Measurement Accuracy

After the delayed acquisition the Landing Radar performed perfectly. There is no indication of loss of radar tracking up to touchdown, even though the downlink data are not continuous because of transmission troubles. During pitch-up at HIGATE the LR antenna was raised into position 2 in 6 seconds. The time-line (Table 1) shows the range switching at 2500 ft slant range. The one and only target redesignation, and the takeover of ROD and attitude control by the Astronauts, leading to program 66. At 50 ft altitude the radar data were inhibited from updating of the state vector to avoid the lunar dust problem. Subsequent radar data show, however, that unlike during Apollo 11 and 12 missions (Refs: 2, 3) the radar never tracked lunar dust. This performance is attributed to the positive rate of descent of about 3 ft/s during the last 50 ft of altitude, which prevented the Doppler trackers from dropping out and from following the relatively weak radar signals originating from the dust. Figure 1 shows the true velocity along the 3 radar velocity beams for the last 60 seconds before touchdown. There is a section between 392054 and 392084 sec LGCT when the velocity on beams 1 and 2 was very low and tracker drop-outs almost happended. Figure 2 shows that in this same time interval the y-component of the radar data was unreliable and showed errors up to 10 ft/s. The figure displays vehicle velocity and radar data points in LR coordinates. The data with errors above 2.5 ft/s were removed by the reasonableness test and did not update the state vector. Note that radar data points at +20 ft/s represent lost radar data because of downlink transmission failure.

Touchdown of the vehicle occurred at about 392114 sec LGCT and was followed by settling of the vehicle. The indicated velocity vector at touchdown was -2.4, +1.2, +2.0 ft/s (antenna coordinates). It indicates a relatively high forward motion of V_z = 2 ft/s. After settling of the vehicle the navigation system error for velocity was 0.03, -0.28, -0.05 ft/s. This error represents the bias error of the radar's velocity sensor.

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S. BOLES, PLANT 25, GAC

APOLLO 14 LANDING, TIME LINE OF ACTIVITIES RELATING TO RADAR OPERATION

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AET	LGCT	EVENT	SOURCE	ENTRY
107:52:00.8	390722.8	V37N63E	MSFN TAB0	2/13
107:52:29.8	390751.8	LR ON	MSFN TAB1	2/11
107:52:45.8	390767.8	RANGE DATA GOOD ON AND OFF	MSFN TAB1	2/11
TO 55:59.8	0961.8			
107:57:33.8	391055.8	LOW SCALE BIT TO '1' (ERROR)**	MSFN TAB1	2/11
107:57:33.8	391055.8	ATTITUDE: 0.6,112.36,358.97	MSFN TAB2	2/11
107:57:37.8	391059.8	PROCEED ENTERED FOR ATT.MANV.	MSFN TAB0	2/11
107:58:13.8	391095.8	FIRST ABORT BYPASS ENTRY (BE-	MSFN TAB0	2/11
TO 58:23.8	1105.8	FORE IGNITION)		
108: 2: 3.8	391325.8	INHIBIT LR READING	MSFN TAB6	2/11
108: 2:21.8	391343.8	V99E	MSFN TAB0	2/11
108: 2:27.8	391349.8	IGNITION	MSFN TAB0	2/11
108: 2:53.8	391375.8	MANUAL THROTTLE UP	GDS TAB7	2/15
108: 2:59.8	391381.8	SECOND ABORT BYPASS ENTRY	GDS TAB0	2/13
TO 3:11.8	1393.8	(AFTER IGNITION)		
108: 3:25.8	391407.8	THIRD ABORT BYPASS ENTRY	GDS TAB0	2/11
TO 3:47.8	1429.8	(AFTER IGNITION)		
108: 4:21.8	391463.8	LANDING SITE CORRECTION BY	GDS TAB0	2/13
TO 4:49.8	1491.8	DELTAZG=2800 FT**		
108: 8:49.8	391731.8	LOW SCALE BIT TO '0' (RECYCLE LR)	MSFN TAB1	2/11
108: 9: 9.8	391751.8	LR VEL DATA GOOD	GDS TAB1	2/13
108: 9:11.8	391753.8	LR RANGE DATA GOOD	GDS TAB1	2/13
108: 9:13.8	391755.8	ENABLE LR READ	GDS TAB6	2/11
108: 9:15.8	391757.8	V06N68 DISPLAYS 2:55 TO HICATE,	GDS TAB0	2/13
TO 9:29.8	1771.8	11557 TO 942 FT DELTAH		
108: 9:35.8	391777.8	V57E**,LRINH TO '1', H=20331 FT	GDS TAB0,5	2/13
108: 9:53.8	391795.8	V16N68 DISPLAYS 2*13 TO HICATE,	GDS TAB0	2/13
TO 10: 5.8	1807.8	160 TO -29 FT DELTAH		
108:10:57.8	391859.8	V16N68 INITIATED..DATA OUTAGE	GDS TAB0	2/13
108:11: 9.8	391871.8	POS1 BIT TO '0', HIGATE**	GDS TAB0	2/13
108:11:15.8	391877.8	POS2 BIT TO '1'	GDS TAB1	2/13
108:11:51.8	391913.8	LOW SCALE BIT TO '1'	GDS TAB1	2/13
108:11:55.8	391917.8	REDESIGNATION BY DELTAYG=-353 FT	GDS TAB23	2/13
108:13: 9.8	391991.8	START OF P66**	GDS TAB0	2/13
108:14:59.8	392101.8	LRINH TO '0', 50 FT ALTITUDE	MSFN TAB5	2/13
108:15:15.8	392117.8	TOUCH DOWN (SETTLING OF STATE V)	GDS TAB18	2/13
108:24:35.8	392677.8	LR OFF		2/11

Table 1. Time-Line of Apollo 14 Landing.

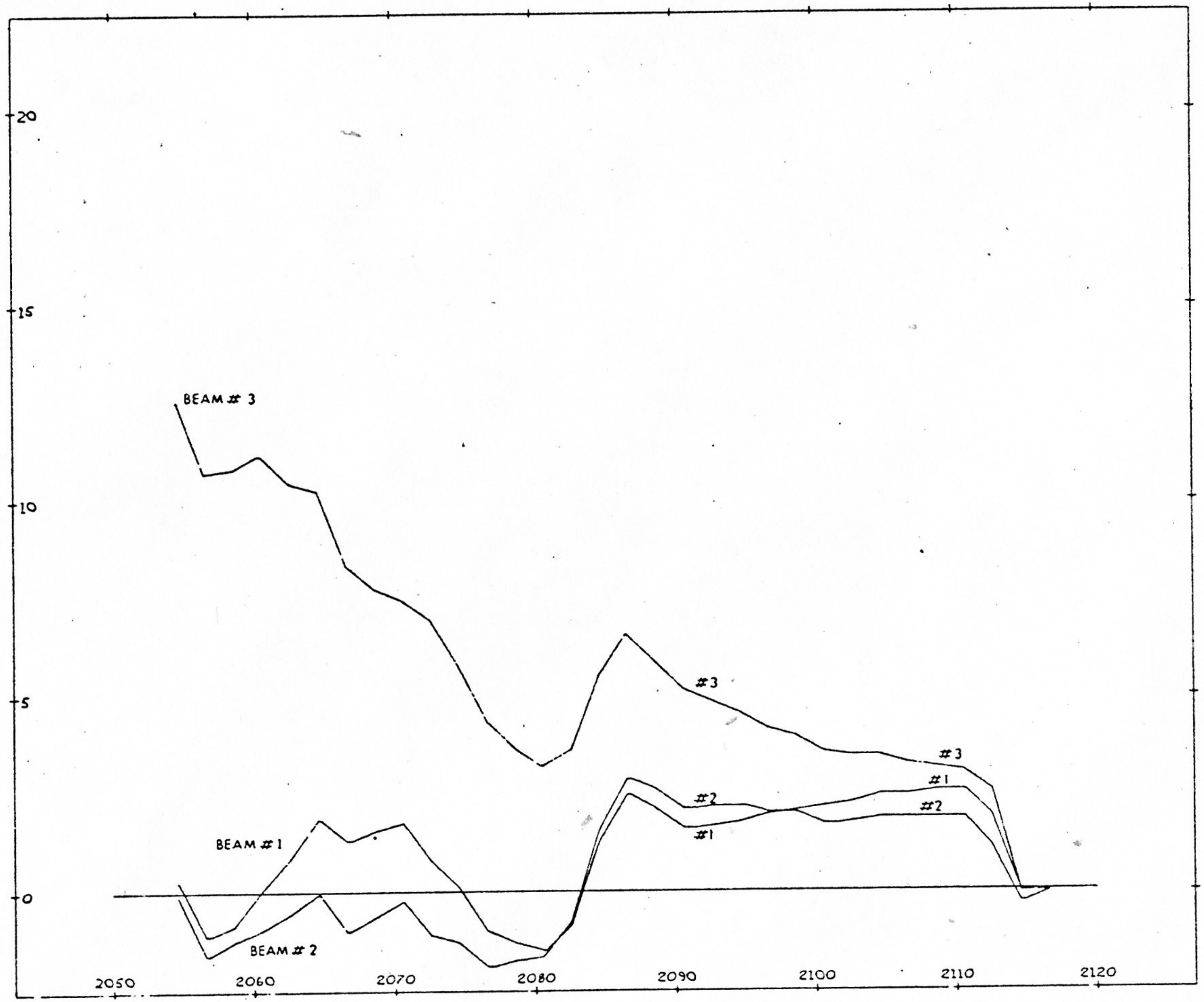

Figure 1. Beam Velocities in ft/s vs. time in sec.

FRAME 002

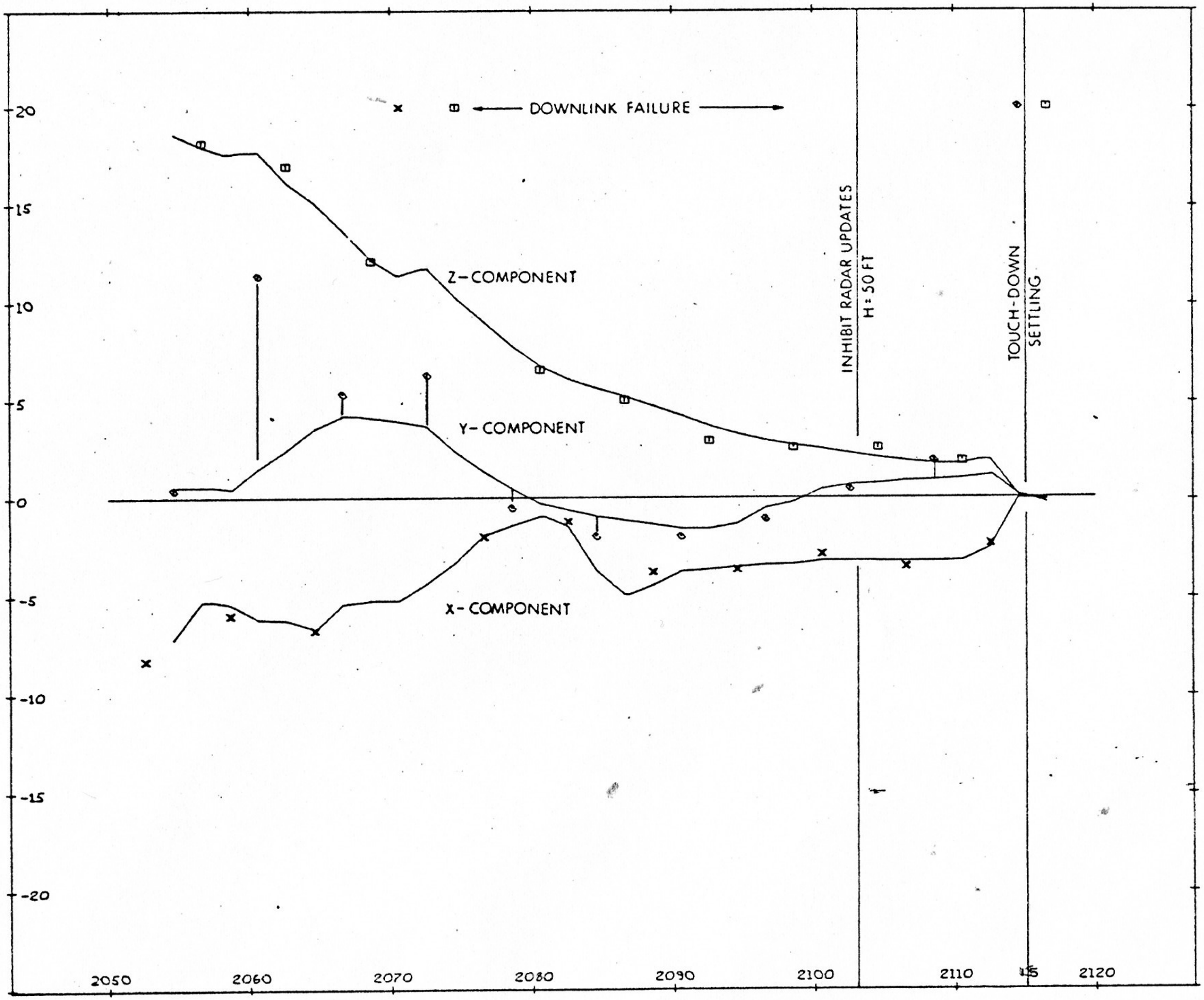

Figure 2. Vehicle Velocity and Radar Data Points in ft/s vs time in sec (Antenna Coordinates)